

1 COMPOSING A REALIGNED IMAGE

2 ABSTRACT OF THE INVENTION

3 This invention provides methods, apparatus and article
4 of manufacture used as a countermeasure to image
5 distorting. The present invention involves
6 automatically detecting the presence of distortion in a
7 presumed distorted image, measuring the magnitude and
8 type of distortion, and finally creating a realigned
9 image. Once image distortion is removed, conventional
10 invisible watermark extraction methods are employed to
11 extract the watermark from the realigned image. The
12 automatic method does not depend on a process of
13 visually examining a composite image and recording the
14 coordinates of pixel locations closest to common image
15 features in a distorted image and reference image.
16 Generally, the presumed distorted image is resized to
17 the same size as the reference image. Reference
18 centers at at least three distinct points that do not
19 form a straight line are selected. At each reference
20 center, a sub-image is excised. Pairs of sub-images,
21 one excised from the reference image and the other
22 excised from the distorted image, having the same
23 reference center are used in the process of removal of
24 the distortion.

1 COMPOSING A REALIGNED IMAGE

2 PRIORITY

3 The present application claims priority of Provisional
4 Application, Application Number 60/117,866, having the
5 same title and a filing date of 01/29/99, by inventors
6 Gordon Braudaway et al.

7 CROSS REFERENCES

8 ~~The present application is related to the following~~
9 ~~applications even dated with the above referenced~~
10 ~~Provisional Application: Application Number 09/240,242,~~
11 ~~entitled, "Recovering Invisible Digital Image~~
12 ~~Watermarks From Distorted Images," by inventors Gordon~~
13 ~~Braudaway et al.; and Application Number 60/117,921~~
14 ~~entitled, "Watermarking and Determining Distortion in~~
15 ~~an Image," by inventors Gordon Braudaway et al., which~~
16 ~~are incorporated herein by reference in their entirety.~~

1 FIELD OF THE INVENTION

2 This application relates to the field of digitized
3 imaging. It is more specifically directed to
4 determining and removal of image distortion from an
5 image.

6 BACKGROUND OF THE INVENTION

7 With the development of means of production and
8 circulation of digital images, and the means of
9 imbedding relatively invisible watermarks into digital
10 images ostensibly to convey ownership of the image,
11 there is now financial incentive to attack an imbedded
12 watermark in an attempt to render it non-extractable.
13 Pixel locations of a watermarked image are presumed to
14 correspond to those in an unmarked original image.
15 Generally, the watermark is imbedded by altering only
16 the values of the pixel components of the original
17 image, not their geometric positions. This may be
18 accomplished employing such methods as described in US
19 Patent 5,825,892 which is incorporated herein by
20 reference in its entirety.

21 Some methods of attacking an imbedded watermark rely on
22 constructing a new image that is a geometrically

1 distorted copy of the watermarked image. This new
2 image is herein referred to as a **distorted copy**.
3 Pixels in the distorted copy are placed at subtly
4 distorted positions relative to those in the
5 watermarked image. Pixel component values in the
6 distorted copy are determined by two-dimensional
7 interpolation of component values of enclosing pixel in
8 the watermarked image. No constraints can be placed on
9 the types of pixel position distortion an attacker
10 might choose to use. To those skilled in the art,
11 however, it is obvious that excessive pixel
12 position-distortion will cause the distorted copy to be
13 a caricature of the watermarked image, thus diminishing
14 or destroying its economic value. Whether a distortion
15 is excessive is a subjective measure. For a distorted
16 copy to be useful, it requires that linear or nonlinear
17 distortion methods that are used by an attacker have to
18 be used sparingly and in such a manner as to produce
19 smoothly varying and relatively small position
20 distortions. This is so as to be essentially
21 unobjectionable and casually unnoticeable to untrained
22 observers. The human visual system, as a qualitative
23 measuring device, can be relied upon to readily detect
24 excessive distortion. It is desirable to have a method
25 of defense that requires little or no limits to be
26 placed on pixel position-distortions produced by the
27 attacking method.

1 SUMMARY OF THE INVENTION

2 In one aspect, the present invention provides a method,
3 apparatus and article of manufacture employing an
4 undistorted reference image relative to which
5 measurements of distortion are made. These employ an
6 automatic method for composing a **realigned** image which
7 does not depend on a process of visually examining a
8 **composite image**, and recording the coordinates of pixel
9 locations closest to common image features in a
10 **distorted image** and **reference image**. If the presumed
11 **distorted image** is not the same size as the **reference**
12 **image**, it is made so by shrinking or enlarging the
13 **reference image**. At the next step, at least three
14 distinct points that do not form a straight line are
15 selected. The integer coordinates of the pixels
16 nearest these points are herein referred to as
17 **reference centers**. At each reference center, a segment
18 of each image, herein referred to as a sub-image, is
19 excised, thus producing for each image as many
20 sub-images as there are distinct points. The
21 horizontal and vertical dimensions of the sub-images,
22 in integer pixel coordinates, are respectively based on
23 the common horizontal and vertical dimensions of the
24 images. A pair of sub-image, one excised from the
25 **reference image** and the other excised from the
26 **distorted image**, having the same reference center are
27 manipulated to determine and/or substantially remove
28 the distortion from the distorted image.

1 Another aspect of the present invention enables a
2 digital image watermark to be extracted from a
3 geometrically distorted copy of a reference image.

4 Other aspects and a better understanding of the
5 invention may be realized by referring to the Detailed
6 Description.

7 **BRIEF DESCRIPTION OF THE DRAWING**

8 These and other objects, features, and advantages of
9 the present invention will become apparent upon further
10 consideration of the following detailed description of
11 the invention when read in conjunction with the drawing
12 figure.

13 **DESCRIPTION OF THE INVENTION**

14 The present invention provides a method, apparatus and
15 article of manufacture by which the distortion in a
16 distorted copy of an image is automatically measured
17 and removed sufficiently well that a relatively
18 invisible image watermark extraction is possible. In
19 an embodiment of the invention, the method employs a
20 **reference image** relative to which measurements of
21 distortion are made. For example, an original unmarked
22 image or a relatively invisibly watermarked copy of the

1 original image, called a watermarked image, serve
2 equally well as the reference image.

3 The automatic method composes a **realigned image** in a
4 way that does not depend on a process of visually
5 examining a **composite image** and recording the
6 coordinates of pixel locations closest to common image
7 features in a **distorted copy** and **reference image**, as is
8 the case in the semiautomatic method of Application
9 Number 09/240,242, cross-referenced herewith.

10 As with the semiautomatic method, if the presumed
11 **distorted copy** is not the same size as the **reference**
12 **image**, it is made so by shrinking or enlarging the
13 **distorted copy** using a method such as pixel
14 interpolation or pixel extrapolation. The distorted
15 copy, after being geometrically resized, is herein
16 referred to as a **geometric alteration**. There are well
17 known automatic and manual methods for resizing images.

18 At the next step, the automatic process differs from
19 the semiautomatic process. At least three common pixel
20 locations in the two images, herein referred to as
21 **reference centers**, not lying in any straight line are
22 required for the automatic method of this invention.

23 In an example embodiment, a coarse but regularly spaced
24 simulated mesh is superimposed identically on each of
25 the two images. Each knot in the mesh forms one of the
26 common pixel locations. The integer coordinates of the
27 pixels nearest each of the at least three common pixel

1 locations are the **reference centers**. At each reference
2 center, a segment of each image, herein referred to as
3 a sub-image, is excised, thus producing for each image
4 as many sub-images as there are common pixel locations.
5 The horizontal and vertical dimensions of the
6 sub-images, in integer pixel coordinates, are based on
7 the common horizontal and vertical dimensions,
8 respectively, of the images. The pair of sub-images,
9 one excised from the **reference image** and the other
10 excised from the **geometric alteration**, having the same
11 reference center are herein referred to as
12 **corresponding sub-images**. A typical embodiment employs
13 three common pixel locations.

14 When the geometric alteration is laid upon the
15 reference image, the intersection of pixels in the
16 reference image with pixels in the geometric alteration
17 is an area of each image called the **safe area**.

18 Although initially the safe area is the entire area of
19 the geometric alteration and the reference image, on
20 subsequent iterations of this realignment method the
21 safe area may be smaller than the reference image.

22 Each sub-image is centered at its respective reference
23 center. If any pixel of a sub-image extends beyond the
24 boundaries of the safe area, such as at the edges of
25 the safe area, then the top or bottom edge of the
26 corresponding sub-images, and the left or right edge of
27 the corresponding sub-images, if also necessary, are
28 repositioned. The two subimages, in unison, are
29 repositioned vertically and horizontally by the minimum

number of pixel locations necessary so that no pixel of either sub-image lies in whole or in part outside of the safe area. The corresponding reference center is adjusted to lie at the center of the repositioned sub-images. Reference centers, after this adjustment process, are referred to as **adjusted centers**, whether they were adjusted or not. Note that in the case where the sub-image horizontal width, I , and vertical height, J , are even integers, such as powers of two, and the coordinates of the sub-images are indexed 0 to $I-1$ and 0 to $J-1$, respectively, the integer coordinates of the center of each sub-image are defined to be $I/2$ and $J/2$. Also note that I should be less than the width and J should be less than the height of the reference image and the geometric alteration.

The n -th pair of sub-images, one from the reference image designated the n -th reference sub-image and a corresponding one from the geometric alteration designated the n -th distorted sub-image, is used to compute a two-dimensional cross-correlation surface relating the distorted sub-image with the reference sub-image image. Those skilled in the art will recognize that there are many methods that may be used to compute or approximate a cross-correlation surface relating the two corresponding sub-images. Regardless of the method used, any method that produces the intended result of determining the horizontal and vertical offsets of the distorted sub-image relative to the reference sub-image that achieves a good match may

1 be employed. For example, a good match has offsets
2 that can not be improved by more than the spacing of
3 1.5 pixels in any direction by using any other means of
4 pattern matching. A better match is readily achievable
5 if the distortions are generally linear. Watermark
6 detection seldom requires a match better than a 0.5-2.0
7 pixel spacing. If required, more complex iteration
8 techniques may be used to achieve a best match.

9 In an example embodiment, forward and inverse discrete
10 Fast Fourier Transforms (FFT's) are used to compute a
11 cross-correlation surface. Note that for methods using
12 FFT's, all sub-images are converted to monochrome, if
13 not already so. The non-integer interpolated
14 horizontal and vertical offsets of the peak of the
15 cross-correlation surface, p_n and q_n , relative to the
16 origin of the cross-correlation surface are used as
17 additive offsets relating the center of the n -th
18 distorted sub-image relative to the n -th corresponding
19 adjusted center. Thus, for each pair of sub-images,
20 the coordinates of the adjusted center are the center
21 on the n -th reference sub-image. The sums of the
22 coordinates of the adjusted center plus the offsets of
23 the peak of the n -th cross-correlation surface become
24 the approximate coordinates of the center of the
25 distorted sub image, $u_n = x_n + p_n$ and $v_n = y_n + q_n$. The
26 coordinates of the offset center of the distorted
27 sub-sub image and the adjusted center, herein referred
28 to as computed pixel coordinates, are analogous to the
29 measured pixel coordinates of common features visually

1 selected from the geometric alteration and reference
2 image of the previously cited semiautomatic method.
3 Using the computed pixel coordinates instead of the
4 measured pixel coordinates, the coefficients matrix, **A**,
5 of the pixel position interpolation equations are
6 computed, as in the semiautomatic method.

7 In another example embodiment, forward and inverse
8 discrete Fast Fourier Transforms (FFT's) are used to
9 compute a modified cross-correlation surface. The
10 magnitudes of the Fourier transform coefficients are
11 modified to make said magnitudes uniform. An inverse
12 Fourier transform is used to compute the modified
13 cross-correlation surface.

14 In yet another example embodiment, a weighted sum of
15 the ordinary and modified Fourier transform
16 coefficients is formed before using an inverse Fourier
17 transform to compute a weighted cross correlation
18 surface.

19 In an embodiment of the automatic method, use of a
20 statistical screen is incorporated into the next step.
21 Use of a statistical screen is generally not needed in
22 the semiautomatic method. Because the selection of
23 sub-images is done indiscriminately, it is possible
24 that some sub-images may have few features (or even
25 none). The cross-correlation surfaces computed from
26 such sub-images may be relatively flat and have a
27 misleading peak. An additional test is used to

1 discriminate against statistical out-flyers that can
2 occur from such misleading peaks. As used herein, an
3 'out-flyer' is a value from a set of values that
4 deviates so greatly from the other values in the set
5 that it is statistically unlikely to be a member of the
6 set.

7 An example statistical screen discriminating against
8 out-flyers is embodied as follows. Each of the pairs
9 of computed pixel coordinates, u_n and v_n , is processed
10 by the interpolation equations to give a **proposed**
11 **reference center**, x_n' and y_n' . The Euclidean distance
12 between the proposed reference center and the
13 corresponding adjusted center, x_n and y_n , is computed
14 for each of the n sub-images. Out-flyers are deleted
15 from the set of n Euclidean distances, largest first,
16 based on their value being above a first threshold
17 value. If any out-flyer is deleted, the offset center
18 of its corresponding distorted sub-image and adjusted
19 center are also deleted. The coefficients, **A**, are
20 recomputed using the undeleted pairs of pixel
21 coordinated, but never with fewer than three pairs of
22 pixel coordinates.

23 From this point on, the automatic and semiautomatic
24 methods generally parallel one another. The square
25 submatrix, **S_A**, of four of the coefficients of the
26 interpolation equations is factored into four primitive
27 image manipulation matrices. The **geometric alteration**

1 is manipulated by the four primitive image
2 manipulations to form the **reoriented image**.

3 The entire restoration process is advantageously
4 repeated iteratively by substituting the previously
5 reoriented image for the geometric alteration before
6 each subsequent iteration. For the automatic method,
7 it has been found that for images with significant
8 distortion, as many as three iterations are warranted.
9 For attacks with more nonlinear distortion, additional
10 iterations may be used to further improve reorientation
11 of the **geometric alteration**. The iteration process is
12 terminated when examination of the Euclidean distances
13 shows that the reduction of all Euclidean distances
14 relative to those from the previous iteration is less
15 than a second threshold. Finally, the **reoriented image**
16 is realigned left or right and up or down relative to
17 the **reference image**, based on the offset coefficients **c**
18 and **f** from the interpolation equations, to form the
19 **realigned image**.

20 An overview of the steps of an example automatic
21 realignment of a presumed distorted copy is shown in
22 the figure. First, if the presumed **distorted copy** is
23 not the same size as the **reference image**, it is shrunk
24 or enlarged to make it the same size using any image
25 resizing method; the resized **distorted copy** is herein
26 referred to as the **geometric alteration**, (102).

1 stead of the manually measured pixel coordinate pairs,
2 as in the referenced semiautomatic method, the
3 coefficients matrix, **A**, of the pixel position
4 interpolation equations is computed, (120), in a manner
5 identical to that used in the cross-referenced
6 semiautomatic method.

7 In this embodiment, the automatic method differs from
8 the cross-referenced semiautomatic method in at least
9 the next steps. Using the pixel position interpolation
10 equations, each of the **distorted reference centers** is
11 converted to form a **proposed reference center**. The
12 Euclidean distance between each of the **proposed**
13 **reference center** and its corresponding **adjusted center**
14 is computed. Those that are "out-flyers", for example
15 those greater than a first threshold, say a spacing of
16 5 pixels, are discarded while at least three are always
17 retained, (122). If any of the **distorted reference**
18 **centers** is discarded, (124), steps (120) through (124)
19 are repeated using only the not-discarded adjusted
20 centers and the not-discarded distorted reference
21 centers. Otherwise, as in the referenced semiautomatic
22 method, the square submatrix, **S_A**, of four of the
23 coefficients is factored into four primitive image
24 manipulating matrices, (126), and the **geometric**
25 **alteration** is manipulated by the four primitive image
26 manipulations to form the **reoriented image**, (128).

27 If any of the primitive manipulations is not
28 sufficiently small, as determined by comparing the

1 incremental changes of the not-discarded Euclidean
2 distances to a second threshold, (130), the **geometric**
3 **alteration** is replaced by the **reoriented image**, (132),
4 and steps (104) through (130) are repeated. Otherwise,
5 the **reoriented image** is offset according to the
6 computed horizontal and vertical offset values to form
7 the **realigned image**, (134). Often, an attempt is made
8 to extract the invisible watermark from the **realigned**
9 **image**, (136).

10 It is noted that the foregoing has outlined some of the
11 more pertinent objects and embodiments of the present
12 invention. This invention may be used for many image
13 or image-like applications. Thus, although the
14 description is made for particular arrangements and
15 methods, the intent and concept of the invention is
16 suitable and applicable to other arrangements and
17 applications. It will be clear to those skilled in the
18 art that modifications to the disclosed embodiments can
19 be effected without departing from the spirit and scope
20 of the invention. The described embodiments ought to
21 be construed to be merely illustrative of some of the
22 more prominent features and applications of the
23 invention. Other beneficial results can be realized by
24 applying the disclosed invention in a different manner
25 or modifying the invention in ways known to those
26 familiar with the art.